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FUZZY LOGIC PROJECT

for the degree of

ADVANCED ROBITICS AND ARTIFICIAL INTELLIGENCE

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Title of the project

Failure Analyzer Application

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General Introduction

This report contains many sections, we will start with a definition of fuzzy logic and neural network and their usages.

Then we will provide the main points of this project such as the goal of this application, steps to create our App and the software chosen.

Also, we will set a list of upgrades that can make our App more advanced. Finally, we will finish with a conclusion that resume all the work done.

Chapter 1

General idea and definitions

This section is devoted to the definition of fuzzy logic, an overview of our application and the goal of its creation.

1.1 Fuzzy logic and neural network

Fuzzy logic is a form of mathematical logic that deals with reasoning that is approximate rather than fixed and exact. It is used to model the vagueness and uncertainty of natural language and decision-making processes. Fuzzy set theory and fuzzy logic are extensions of classic set theory and logic, which have been largely used in computer science and engineering. The ability of fuzzy inference systems (FISs) to deal with uncertainty, represent vague concepts, and connect human language to numerical data, allowed fuzzy logic to be successfully exploited in different contexts, and in knowledge- or datadriven applications, as in the case of decision-making, modeling and control, classification, and regression problems. A neural network is a type of machine learning model that is inspired by the structure and function of the human brain. It consists of layers of interconnected "neurons" that can learn to recognize patterns and make predictions based on input data. Neural networks are used for a wide range of tasks such as image recognition, natural language processing, and decision-making.

1.2 Description of the Application and motivation

A fuzzy logic application that determines the degree of failure of machines can be useful in identifying potential issues and prioritizing maintenance and repair needs. The application uses fuzzy logic to evaluate input data, such as sensor readings, machine performance metrics, and historical failure data, to determine the likelihood of different types of failures. The app can classify the failure as catastrophic, major, or minor, which can help in decisionmaking and scheduling maintenance. A catastrophic failure means the machine has stopped working and cannot be repaired, major failure means the machine can be repaired but it will take a long time and minor failure means the machine can be repaired quickly. Overall, the application can help to improve the reliability and availability of machines by identifying potential issues early on and prioritizing maintenance and repair needs

Chapter 2

Software and platforms used

2.1 Anaconda and Jupyter notebook

to write the code in python we chose Anaconda and Jupiter notebook Anaconda is a distribution of Python and R for scientific computing and data science. It comes with a package manager called Conda, which makes it easy to install and manage libraries and dependencies. Anaconda also includes several useful tools such as Jupyter Notebook and Spyder for data exploration and development. Jupyter Notebook is an open-source web-based interactive development environment (IDE) that allows users to create and share documents that contain live code, equations, visualizations, and narrative text. It supports over 40 programming languages including Python, R, and Julia. Jupyter Notebook is commonly used in data science, machine learning, and scientific computing for data cleaning, transformation, visualization, and analysis.

Figure 2.1: Anaconda logo

Figure 2.2: Jupyter logo

2.2 LyX 2.3

LyX is a document processor and document preparation system based on the LaTeX typesetting system. LyX 2.3 is the latest version of LyX as of 2021. It is a free and open-source software that runs on various platforms including Windows, macOS, and Linux. LyX allows users to create professional-looking documents with a wide range of features including mathematical equations, tables, figures, and cross-references. It also supports various document formats such as LaTeX, PDF, and HTML. LyX 2.3 includes new features such as improved support for LaTeX packages, new citation styles, and a new user interface for managing bibliographies.

Figure 2.3: Lyx logo

Chapter 3

Project Context

In this part we will define the outputs and inputs required for the execution of the fuzzy application and, we will provide the dataset we prepared

3.1 List of inputs

Our inputs are the state of the machines, depending on the diagnostic and the observations of the user he can choose which current state of the machine then the application will do the rest to classify the degree of the failure we made a list of possible factors which can affect the functionality of industrial machines such as:

- **Unusual noises**

<u>Humming:</u> Humming noise is often caused by the operation of electrical or mechanical components, such as motors, generators, or pumps.

<u>Rattling:</u> Rattling noise is often caused by loose or poorly fitting parts within the machine. It can also be caused by imbalanced or worn components.

<u>Grinding:</u> Grinding noise is often caused by the friction of metal parts moving against each other and can be a sign of a problem with the machine's bearings or gears.

In order to troubleshoot and fix these types of noise problems, it is important to first identify the source of the noise and then determine the cause. This may require the use of specialized equipment, such as vibration sensors or sound level meters, and may also involve disassembling and inspecting the machine's components.

- **Vibrations**

<u>Transient vibrations:</u> These are short-term vibrations that occur during the start-up or shut-down of a machine.

<u>Continuous vibrations</u>: These are long-term vibrations that occur continuously while the machine is in operation.

<u>Forced vibrations:</u> These are caused by an external force applied to the machine, such as unbalanced forces, misalignment, or unevenly distributed loads.

It is important to monitor and analyze the vibrations of an industrial machine to ensure its proper functioning and prevent damage.

- **Leaks**

Air leaks: These are leaks of compressed air from pipes, fittings, or other parts of the pneumatic system. Air leaks can reduce the efficiency of the system and cause increased energy consumption.

Oil leaks: These are leaks of lubricating oil from bearings, seals, gaskets, or other parts of the machine. Oil leaks can cause reduced lubrication and damage to the machine.

Gas leaks: These are leaks of gases, such as steam or natural gas, from pipes, fittings, or other parts of the machine. Gas leaks can be dangerous and can cause explosions or fires.

It is important to regularly inspect and maintain industrial machines to detect and repair leaks in order to prevent damage and ensure safe and efficient operation.

- **Smells**

Acrid smell: This could be caused by the presence of ozone, which could indicate a problem with the machine's electrical system.

Metallic smell: This could indicate the presence of metal shavings or other debris in the machine, which could be a sign of wear or damage to mechanical components.

Burning smell: This could indicate that there is a problem with the machine's electrical system, such as a short circuit or overheated motor. It could also be caused by friction or overheating of mechanical components.

It is important to carefully investigate the source of any unusual smells coming from an industrial machine to determine the cause and take appropriate action to address the issue. To resume all the inputs, we created these graphs:

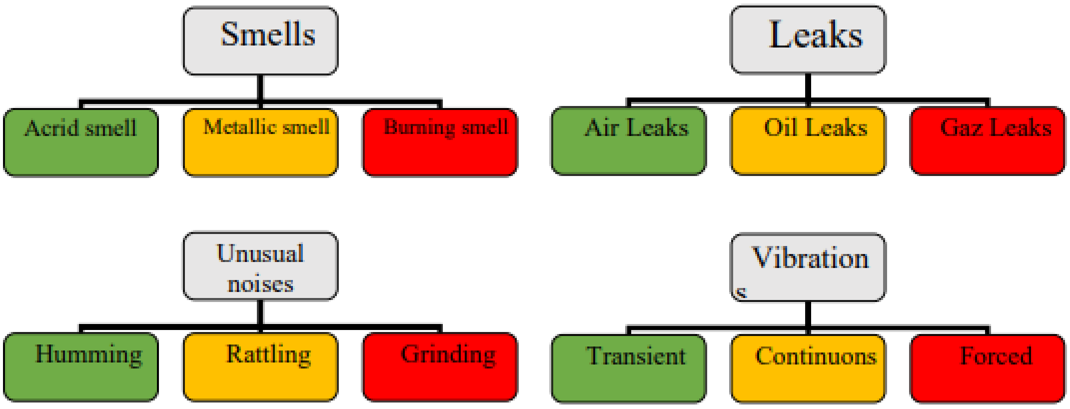

Figure 3.1: Inputs graphs

3.2 List of outputs

The outputs displayed with the application are basically the degrees of failure. There are several degrees of failure that can occur in an industrial machine, depending on the severity of the problem and the impact it has on the machine's operation. Here are three examples of different degrees of failure that can occur in an industrial machine:

- **Minor failure:**

A minor failure is a problem that does not significantly impact the operation of the machine, and it can usually be repaired without interrupting production. Examples of minor failures might include a small mechanical problem such as a malfunctioning sensor or a minor electrical issue such as a blown fuse.

- **Major failure:**

A major failure is a more serious problem that significantly impacts the operation of the machine and may require more extensive repairs or downtime to fix. Examples of major failures might include a malfunctioning control system, a broken gear, or a damaged bearing.

- **Catastrophic failure:**

A catastrophic failure is a severe problem that results in the complete failure of the machine and may require extensive repairs or replacement. Examples of catastrophic failures might include a structural failure, a severe electrical problem, or a major mechanical failure.

Overall, the degree of failure in an industrial machine can vary widely, and it is important to identify and address problems as soon as possible to minimize the impact on the machine's operation.

3.3 Dataset

The dataset contains more detailed information about the types of failures that a machine can have. They are generally classified as electrical failures and mechanical failures.

- **Electrical problems**

Electrical problems are common in industrial machines, and they can cause equipment failures and downtime if not addressed in a timely manner. Some common electrical problems that may affect industrial machines include:

- Power supply issues: Industrial machines may be affected by problems with the power supply, such as voltage fluctuations, power surges, or outages. These problems can damage or disrupt the operation of electrical components and systems.

- Electrical overload: Industrial machines may be damaged or malfunction if they are overloaded with electrical current. This can be caused by problems such as short circuits, faulty wiring, or overloading of electrical circuits.

- Control system issues: Industrial machines often rely on control systems to operate, and problems with these systems can cause equipment failures or reduced performance. This may include issues such as faulty sensors, damaged control panels, or programming errors.

- Motor problems: Motors are a critical component of many industrial machines, and problems with motors can lead to equipment failures or reduced performance. This may include issues such as burnout, overloading, or bearing failure.

- Corrosion: Corrosion of electrical components can lead to problems such as reduced conductivity, increased resistance, and electrical failure.

-Poor maintenance: Neglecting regular maintenance and upkeep of electrical components can lead to problems such as corrosion, wear and tear, and reduced performance

Overall, it is important to regularly inspect and maintain industrial machines to prevent or identify and address electrical problems before they become serious. This may involve replacing worn or damaged components, repairing, or replacing faulty wiring, and ensuring that the machine is properly grounded and protected against power surges and other electrical problems.

Mechanical failures

Mechanical problems are common in industrial machines, and they can cause equipment failures and downtime if not addressed in a timely manner. Some common mechanical problems that may affect industrial machines include:

- Wear and tear: Over time, mechanical components such as bearings, gears, and belts can wear out or become damaged, leading to equipment failures or reduced performance.

- Lubrication issues: Proper lubrication is essential for the smooth operation of mechanical components, and insufficient lubrication or the use of the wrong lubricant can lead to problems such as increased wear and tear, overheating, and seized components.

- Alignment issues: Misalignment of mechanical components can lead to problems such as increased wear and tear, vibration, and reduced performance.

- Poor maintenance: Neglecting regular maintenance and upkeep of mechanical components can lead to problems such as increased wear and tear, corrosion, and reduced performance.

Overall, it is important to regularly inspect and maintain industrial machines to prevent or identify and address mechanical problems before they become serious. This may involve lubricating and replacing worn or damaged components, aligning mechanical components, and cleaning and maintaining the machine to ensure its proper operation.

Here is the table that presents our dataset:

Types of failure	Failers	Description of failures	Degree of failure
Electrical Failures	Power supply issues	Voltage flufctuations	Minor
		Power surges	Major
		Power outages	Ctastrophic
	Electrical overload	Short circuits	Ctastrophic
		Faulty wiring	Major
		Electrical motor insultation failure	Ctastrophic
	Control system issues	Reduced performance	Major
		Delayed response time	Major
		Damaged control panel HMI	Minor
		Programming errors	Ctastrophic
	Corrosion	Reduced conductivity	Major
		Increased resistance	Major
		Electrical failure	Minor
Mechanical failures	Structural issues	Bending	Minor
		Cracking	Major
		Damage to the support structure	Ctastrophic
	Alignment issues	Misalignment of mechanical components	Ctastrophic
	Contamination	Jamming	Major
		Damage to components	Ctastrophic
	Lubrification issues	Overheating	Major
		Increasing wear and tear	Major
		Lack of lubrification or use oof bad one	Major

Table 3.2: Dataset

Chapter 4

Flowchart of code and results

4.1 Initializing environment and libraries

Simpful library

Is a user-friendly Python library designed to define FISs for any purpose. Simpful provides a lightweight Application Programming Interface (API) for fuzzy reasoning, including a set of classes and methods to intuitively define fuzzy sets and fuzzy rules, and to perform fuzzy inference. A noticeable feature of Simpful is that fuzzy rules can be constructed by means of strings of text written in natural language, thus simplifying the definition of fuzzy rule bases.

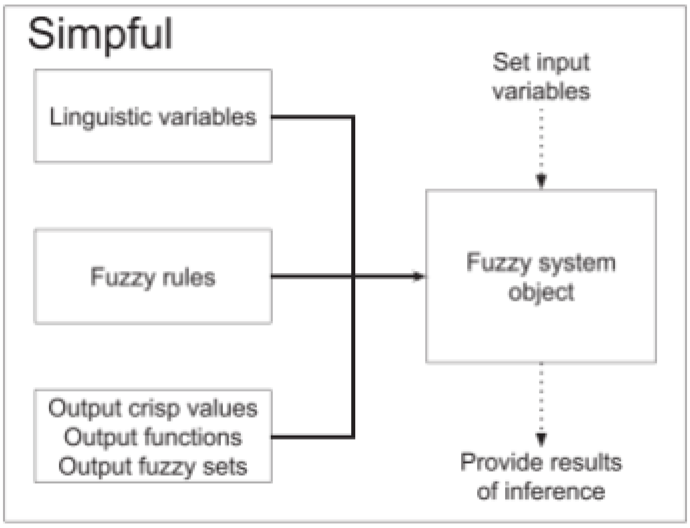

Figure 4.1: Graphical representation of the Fuzzy System object in Simpfu

4.2 Organization of the code

This is Python code that creates a fuzzy inference system using the "Simpful" library. The code defines several linguistic variables, such as "noises", "vibration", "leaks" and "smells" with a set of fuzzy sets that correspond to different levels of each variable. It also defines an output linguistic variable "failure" with fuzzy sets for different levels of failure. After that, it defines several fuzzy rules that relate the input variables to the output variable, **for example:**

if leaks are of type "Gaz" and smells are "Burning" and the vibration is "Transient" or "Continuous" or "Forced" and noise is "Humming" or "Rattling" or "Grinding" then the failure is "Catastrophic".

These lines for tare he import of the library and to create a fuzzy system object named FS

```python
from simpful import *

 # Create a fuzzy system object
FS = FuzzySystem()
```

The next code is to define the input fuzzy sets

```python
# Define fuzzy sets and linguistic variables
S_1 = FuzzySet(function=Triangular_MF(a=0, b=2, c=4), term="Humming")
S_2 = FuzzySet(function=Triangular_MF(a=3, b=5, c=7), term="Rattling")
S_3 = FuzzySet(function=Triangular_MF(a=6, b=8, c=10), term="Grinding")
FS.add_linguistic_variable("noises", LinguisticVariable([S_1, S_2, S_3], concept="types of noises", universe_of_discourse=[0,10])

F_1 = FuzzySet(function=Triangular_MF(a=0, b=2, c=4), term="Transient")
F_2 = FuzzySet(function=Triangular_MF(a=3, b=5, c=7), term="Continuous")
F_3 = FuzzySet(function=Triangular_MF(a=6, b=8, c=10), term="Forced")
FS.add_linguistic_variable("Vibration", LinguisticVariable([F_1, F_2,F_3], concept="vibration degree", universe_of_discourse=[0,1

L_1 = FuzzySet(function=Triangular_MF(a=0, b=2, c=4), term="Air")
L_2 = FuzzySet(function=Triangular_MF(a=3, b=5, c=7), term="Oil")
L_3 = FuzzySet(function=Triangular_MF(a=6, b=8, c=10), term="Gaz")
FS.add_linguistic_variable("Leaks", LinguisticVariable([L_1, L_2, L_3], concept="type of leaks", universe_of_discourse=[0,10]))

M_1 = FuzzySet(function=Triangular_MF(a=0, b=2, c=4), term="Acrid")
M_2 = FuzzySet(function=Triangular_MF(a=3, b=5, c=7), term="Metallic")
M_3 = FuzzySet(function=Triangular_MF(a=6, b=8, c=10), term="Burning")
FS.add_linguistic_variable("Smells", LinguisticVariable([M_1, M_2, M_3], concept="type of smells", universe_of_discourse=[0,10])
```

And these lines are for the output fuzzy sets

```python
# Define output fuzzy sets and linguistic variable
T_1 = FuzzySet(function=Triangular_MF(a=0, b=2, c=4), term="Minor")
T_2 = FuzzySet(function=Triangular_MF(a=3, b=5, c=7), term="Major")
T_3 = FuzzySet(function=Triangular_MF(a=6, b=8, c=10), term="Catastrophic")
FS.add_linguistic_variable("failure",LinguisticVariable([T_1, T_2, T_3],concept="degree of failure",universe_of_discourse=[0,25])
```

We can type the rules like this

```python
# Define fuzzy rules
R1 = "IF (Leaks IS Gaz) AND (Smells IS Burning) AND ((Vibration IS Transient) OR (Vibration IS Continuc
R2 = "IF (noises IS Rattling) AND (Leaks IS Oil) AND (Vibration IS Continuous) AND (Smells IS Metallic)
R3 = "IF (noises IS Humming) AND (Leaks IS Air) AND (Vibration IS Transient) AND (Smells IS Acrid) THEN
R4 = "IF (Vibration IS Continuous) AND (Smells IS Metallic) AND (noises IS Grinding) AND (Leaks IS Oil)
R5 = "IF (noises IS Humming) AND (Leaks IS Oil) AND (Smells IS Acrid) AND (Vibration IS Continuous) THE
FS.add_rules([R1, R2, R3, R4, R5])
```

Finally, these lines are for settings the value of each input and the last step is the deffuzzification and displaying the result

```python
# Set antecedents values
FS.set_variable("noises", 4)
FS.set_variable("Vibration", 4)
FS.set_variable("Smells", 5)
FS.set_variable("Leaks", 4)

# Perform Mamdani inference and print output
#print(FS.Mamdani_inference(["failure"]))
result = FS.Mamdani_inference(["failure"])
value = result.get("failure", 0)
if value <= 3:
    print("The failure degree is Minor")
elif value > 3 and value <= 6 :
    print("The failure degree is Major")
elif value > 8:
    print("The failure degree is Catastrophic")
```

4.3 Results

```
  ____  __  _  _  ____  ____  _  _  __
 / ___)(  )( \/ )(  _ \(  __)/ )( \(  ) v2.9.0
 \___ \ )( / \/ \ ) __/ ) _) ) \/ (/ (_/\
 (____/(__)\_)(_/(__)  (__)  \____/\____/

 Created by Marco S. Nobile (m.s.nobile@tue.nl)
 and Simone Spolaor (simone.spolaor@unimib.it)

The failure degree is Major
```

4.4 Upgrades to our project

We created an HTML pageweb that can improve the control and usage of our application we just need to link it with our code and execute it. We can also use Anvil.com is it a website that creates web applications using only python code.

General Conclusion

To resume the work done we state the steps to achieve the result which are choosing the idea of this app and its benefits start looking for information about types of failures and their degrees start coding on our notebook then testing the application.

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